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NU: Alexander VON GAISBERG

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LITERAL TRANSLATION OF PCT INTERNATIONAL APPLICATION
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Electromagnetic Actuator and Method for Adjusting Said
Electromagnetic Actuator

The invention relates to an electromagnetic actuator according
to the preamble of the patent claim 1 and a method for the ad-
justing of an electromagnetic actuator according to the preamble
of the patent claim 6.

An electromagnetic actuator for operating a gas exchange valve
in an internal combustion machine is known from the DE 196 31 909
A1. The actuator comprises two electromagnets arranged at a
spacing distance relative to one another, and an armature that
is in operative connection with the gas exchange valve and that
is movable back and forth by magnetic force between the electro-
magnets against the force of two respectively counteracting
springs. The actuator further comprises setting means, with
which the position of the armature is set to the geometric center
position between the two end positions of the armature in connec-
tion with de-energized electromagnets. In this regard, the high
dependency of the energy requirement of the actuator on produc-
tion tolerances is found to be disadvantageous.

Therefore, the invention is based on the object to provide an
electromagnetic actuator according to the preamble of the patent
claim 1, of which the energy requirement slightly depends on the
production tolerances. The invention is further based on the
object to provide a method according to the preamble of the

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patent claim 6, through which the dependency of the energy requirement of the actuator on production tolerances is minimized.

The object is achieved in an electromagnetic actuator according to the preamble of the patent claim 1 by the characterizing features of the patent claim 1, and in a method according to the preamble of the patent claim 7 by the characterizing features of the patent claim 7.

Advantageous embodiments and further developments are evident from the dependent claims.

According to the invention, the springs are pre-stressed in such a manner that the same energy will be stored in both springs in connection with a compression of the springs respectively by a spring travel distance prescribed by the limited stroke travel distance of the armature. Hereby one achieves, that the armature, when it is released from its two end positions and freely oscillates, will approach close to the two electromagnets to the same extent. As a result thereof, the influence of production-necessitated tolerances of the components, and especially of the springs, on the oscillating behavior of the armature is reduced. Moreover, the total energy requirement of the actuator is optimized, because both electromagnets comprise the same current requirement due to the armature approaching equally closely to the two electromagnets. Namely, if the armature would approach more closely to the one electromagnet than to the other during the free oscillation, then the current requirement of the one electromagnetic would drop by a certain amount, but the current

requirement of the other electromagnet would increase by a multiple of this amount, so that also the total energy requirement of the actuator would increase relative to the optimal value.

Preferably, at least one of the springs comprises a non-linear spring characteristic, advantageously a characteristic with a maximum value at a position of the armature lying between the electromagnets. Due to the non-linear spring characteristic of one or both of the springs, it is on the one hand ensured that the armature is accelerated with large forces, which has a high switching frequency as a result, and on the other hand one thereby achieves that small forces act in the end positions of the armature, so that also the energy requirement of the actuator for holding the armature in its end positions is small.

For the adjustment of this electromagnetic actuator, for each spring the course or progression of the spring force is measured, which spring force arises if the respective spring is compressed by a spring travel distance corresponding to the stroke travel distance of the armature. The energy, which is stored in the respective spring due to the compression thereof, is determined from the measured curves or progressions of the spring forces. Next, the pre-stressing of one or both springs is set in such a manner that the same energy is stored in both springs.

The adjustment of the actuator can be carried out during the manufacturing of the actuator, but an adjustment during the operation is also conceivable, in order to compensate changes of

operating values or parameters, as they may arise, for example, due to temperature effects, wear, or aging.

The invention will be described in greater detail below in connection with an example embodiment, with reference to the Figures, wherein:

Fig. 1 shows an electromagnetic actuator for operating a gas exchange valve in an internal combustion machine,

Fig. 2 shows a first force versus travel distance diagram with spring characteristic curves,

Fig. 3 shows a second force versus travel distance diagram with spring characteristic curves.

According to the Fig. 1, the actuator according to the invention comprises a push rod or valve stem 4 that is in force transmitting cooperation with a gas exchange valve 5, an armature 1 secured with the valve stem 4 perpendicularly to the valve stem longitudinal axis, an electromagnet 3 acting as a closing magnet as well as a further electromagnet 2 acting as an opening magnet, which is arranged spaced apart from the closing magnet 3 in the direction of the valve stem longitudinal axis. The electromagnets 2, 3 respectively comprise an energizing or exciting coil 20 or 30, and pole surfaces lying across from one another. By means of an alternating energization of both electromagnets 2, 3, that is to say the exciting coils 20 or 30, the armature 1 is moved back and forth between the electromagnets 2, 3 along a

stroke travel that is limited by the electromagnets 2, 3. A
spring arrangement with a first spring 61 acting in the opening
direction onto the armature 1 and a second spring 62 acting in
the closing direction onto the armature 1 effectuate that the
armature 1 is held in a neutral equilibrium position between the
electromagnets 2, 3 in the de-energized condition of the exciting
coils 20, 30. Furthermore, adjusting or setting means 71, 72 for
setting the pre-stressing of the springs 61, 62 are provided.
The setting means 71, 72 may, for example, be embodied as disks,
which effectuate a compression of the springs 71, 72, and thereby
prescribe the pre-stressing of the respective springs 71, 72.
They may, however, also be controllably embodied, and enable a
stepless variation of the pre-stressing.

For starting the actuator, one of the electromagnets 2, 3 is
energized, that is to say switched on, by applying an exciting
voltage to the corresponding exciting coil 20 or 30, or a tran-
sient start-up oscillation routine is initiated, by means of
which the armature 1 is first set into oscillation by alternating
energization of the electromagnets 2, 3, in order to strike
against the pole surface of the closing magnet 2 or the pole
surface of the opening magnet 3 after a start-up oscillation
transient time.

With a closed gas exchange valve 5, the armature 1 lies against
the pole surface of the closing magnet 3 as shown in Fig. 1, and
it is held in this position - the upper end position - as long
as the closing magnet 3 is energized. In order to open the gas
exchange valve 5, the closing magnet 3 is switched off, and next

the opening magnet 2 is switched on. The first spring 61 acting in the opening direction accelerates the armature 1 through or beyond the rest position. By means of the opening magnet 2 which is now energized, additional kinetic energy is supplied to the armature 1, so that it reaches the pole surface of the opening magnet 2 despite possible friction losses, and there - at the bottom end position which is shown with dashed lines in Fig. 1 - is held until the switching off of the opening magnet 2. For the renewed closing of the gas exchange valve 5, the opening magnet 2 is switched off and the closing magnet 3 is next again switched on. The armature 1 is thereby moved by the second spring 62 to the closing magnet 3 and is held there on its pole surface.

The stroke travel distance l_m of the armature 1, over which the armature 1 travels - the motion of the armature 1 is referred to as flight in the following - is limited due to the prescribed spacing distance between the electromagnets 2, 3. The progressions of the spring forces of the two springs 61, 62, that is to say the forces with which the springs 61, 62 act on the armature 1, are dependent on the armature position I and can be described in connection with spring characteristic curves. In the force versus travel distance diagram of Fig. 2, the spring characteristic curve of the first spring 61 is referenced with F_1 , and the spring characteristic curve of the second spring 62 is referenced with F_2 . During the flight of the armature 1 from the upper end position to the lower end position, that is to say from the armature position 0 to the armature position l_m , the force of the first spring 61 increases at first from a holding value F_{11} to

ing times, despite the small holding value F_{11} . Due to the small holding value F_{11} , on the other hand, the current requirement for holding the armature 1 in its upper end position, and therewith the energy requirement of the actuator, is small.

5 In the force versus travel distance diagram according to Fig. 3, the spring characteristic curve F_2 of the second spring 62, with an increasing spacing distance I between armature 1 and closing magnet 2, comprises at first a decreasing progression, then an increasing progression, and thereafter again a decreasing progression. The areas A_1 , A_2 under the spring characteristic curves F_1 , F_2 of the springs 61, 62 are once again equally large. For these spring characteristic curves F_1 , F_2 it is shown to be advantageous, that the difference ΔF between the two spring characteristic curves F_1 , F_2 , that is to say the resulting force acting on the armature 1, is large for a large range of the spacing distance I between the armature 1 and closing magnet 3. As a result of that, the gas exchange valve 5 may also be opened against a combustion chamber internal pressure, that is to say the energy requirement of the opening magnet 2 is small due to the high resulting force ΔF that is effective during the opening process.

The adjustment of the actuator is carried out before the installation of the actuator in the internal combustion machine. Thereby, first the pre-stressing of the second spring 62 is adjustingly set to the end value F_{20} , at which a secure or reliable closing of the gas exchange valve 5 is ensured. Next, the second spring 62 is compressed by the spring travel distance

corresponding to the stroke travel distance l_m of the armature 1, and the progression of the spring force, which results thereby, is measured section-wise and integrated section-wise over the spring travel distance. The result of this integration corresponds to the energy that is stored in this context in the second spring 62. Thereby, the measurement of the spring force can be carried out by means of a load cell or a measuring gage.

5 The energy that is stored in the first spring 61 if the armature 1 is moved from its lower end position to its upper end position, is also measured in the same manner as described above, namely by measuring the progression of the spring force of the first spring 61 that results from the armature motion, and by integration of this progression over the spring travel distance, through which the first spring 61 is thereby compressed. Next, the energy values that have been determined in this manner are compared with one another, and the pre-stressing of the first spring 61 is adjustingly set in such a manner so that the same energy is stored in the two springs 61, 61, if these are compressed by the stroke travel distance l_m . The actuator is only installed into the internal combustion machine after this adjustment.

10 In the present example embodiment, the actuator is adjusted before placing it into operation. Also conceivable, however, are an adjustment during the operation, and an after-adjustment dependent on operating parameters. In this case, the adjusting or setting means are controllably embodied, and the progressions of the spring forces are measured with measuring means, onto which the springs act, for example with pressure sensors, espe-

cially with piezocrystals. The adjusting or setting means are then controlled by control means, dependent on the measured spring forces, in such a manner so that the same energy is stored in both springs in connection with the maximum compression of the
5 springs 61, 62 that is possible during the operation.

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